Missions and Development Requirements for the MITEE Nuclear Thermal Propulsion Engine

by
James Powell, George Maise, and John Paniagua
Plus Ultra Technologies, Inc.
Stony Brook, New York
www.newworlds.com

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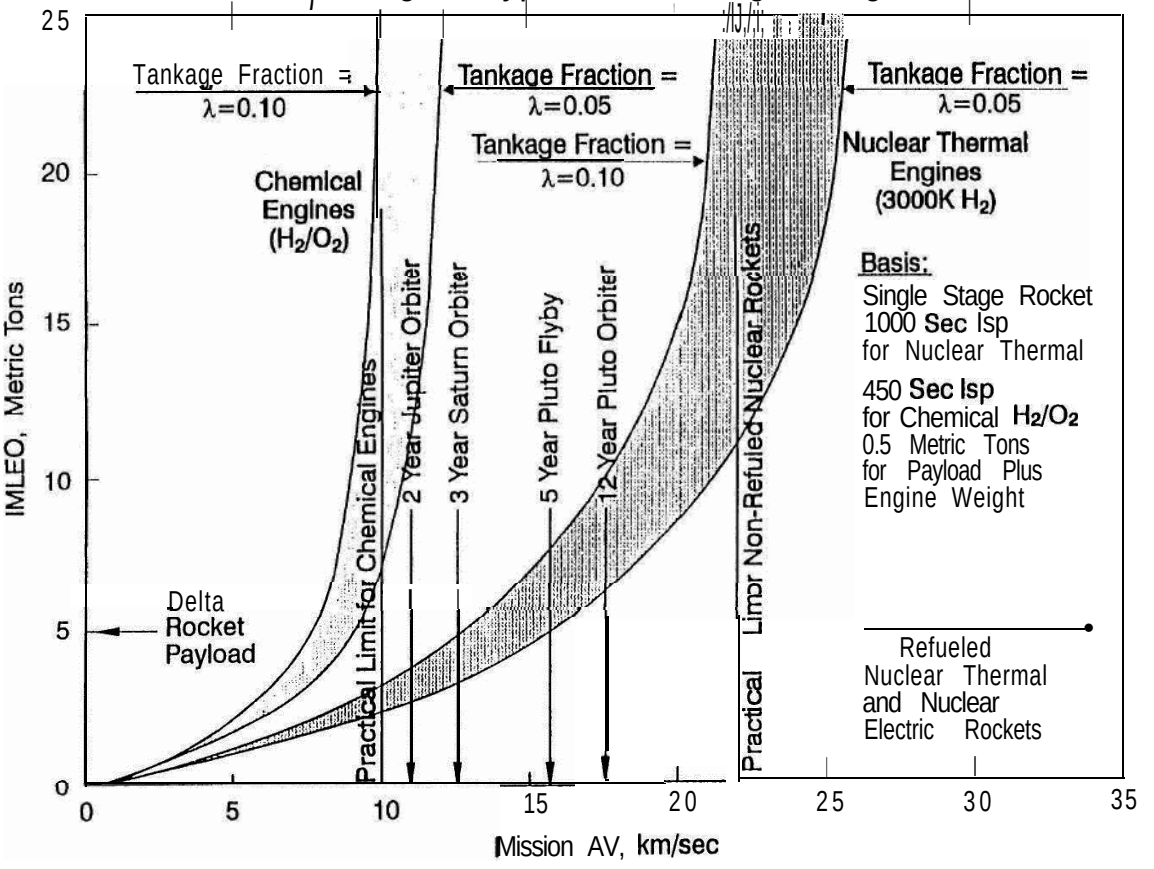
Backgrouncl

- Nuclear Thermal Propulsion Offers Breakthroughs for Outer Planetary Exploralion
- Enables Much Faster, Missions to Outer Planets Without Need for Planetary Gravity Assists, and With Smaller, Lower Cost Launch Vehicles
- Enables New, Unique Exploration Missions That Are Not Possible With Chemical Rocltels, e.g.,
  - Jupiter Atmospheric Flyer
  - Europa Sample Return
  - Pluto Orbiter
- Nuclear Thermal Engines Can Be Built in Very Small Sizes With Very High Performance
  - -100 kg, 1000 set I,,, -20,000 Newtons Thrust
- Small MITE Engine Could Be Ready By 2010, Using Existing Technology Base

Initial Mass in Low Earth Orbit (IMLEO) as a Function of Mission ΔV, Engine Type and Tankage Weight Fraction



The MITEE Approach for a Compact, Ultralight Nuclear Engine

✔ ❖ Multiple Pressure Tube Construction
- ✔ No Separate Reactor Vessel
- ✔ Pressure Tubes Contain Individual Nozzles

❖ Lightweight ^{7}LiH Moderator
- ✔ Option for Liquid I-I, Reflector

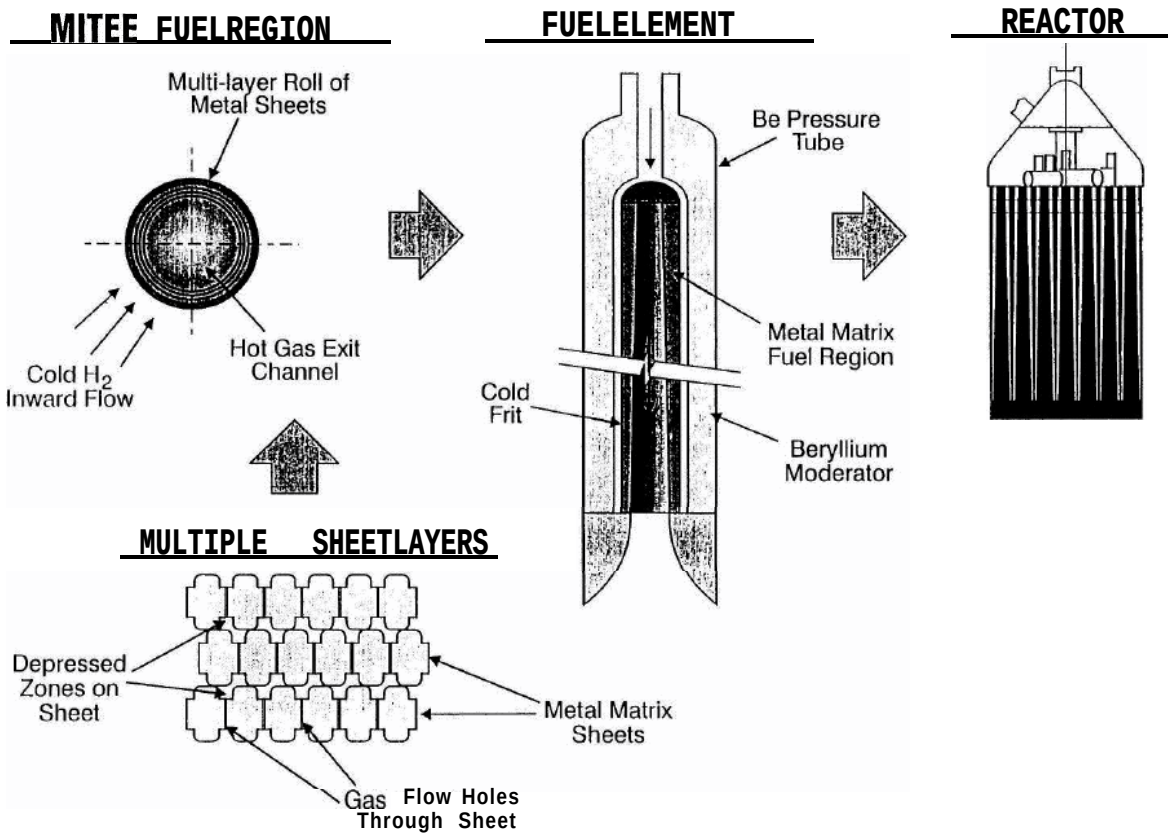
✔ ❖ W/UO_2 and Mo/UO_2 Metal Matrix Composite Perforated Fuel Sheets

❖ Radial Coolant Flow Through Annular Fuel **Element**
- ✔ Hot and Cold Frits are Also Fuel Sheets

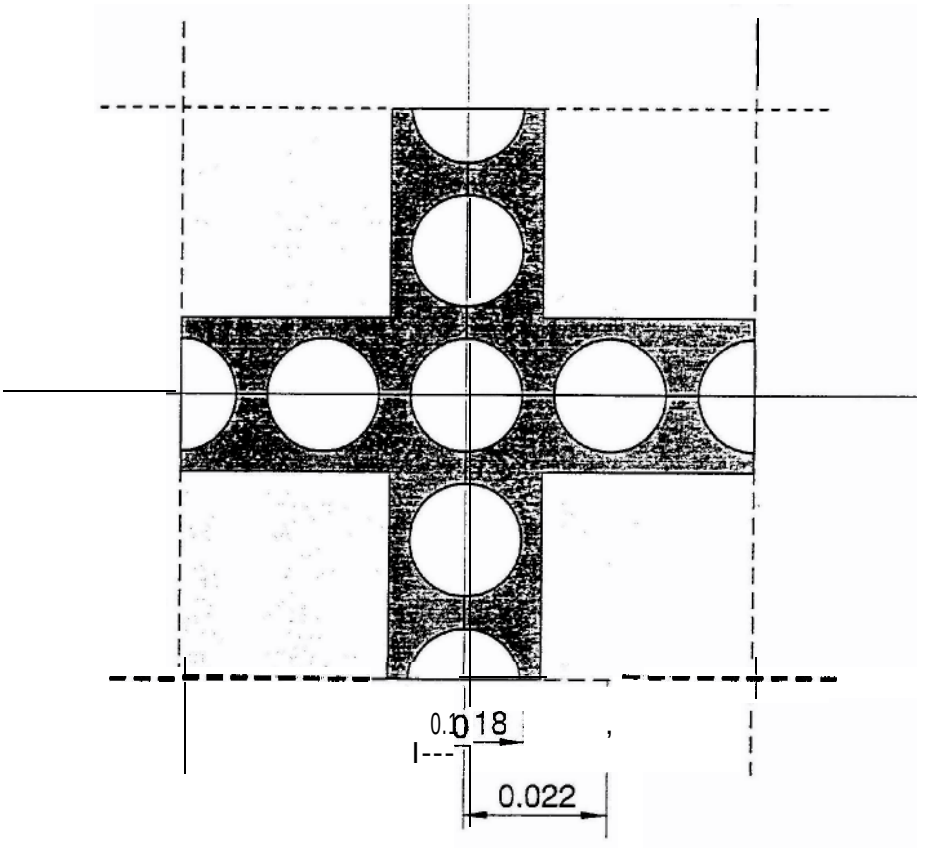
❖ Several Fissile Fuel Options
- ^{235}U
- ✔ ^{233}U
- ✔ ^{242m}Am

✔ Differs from PBR

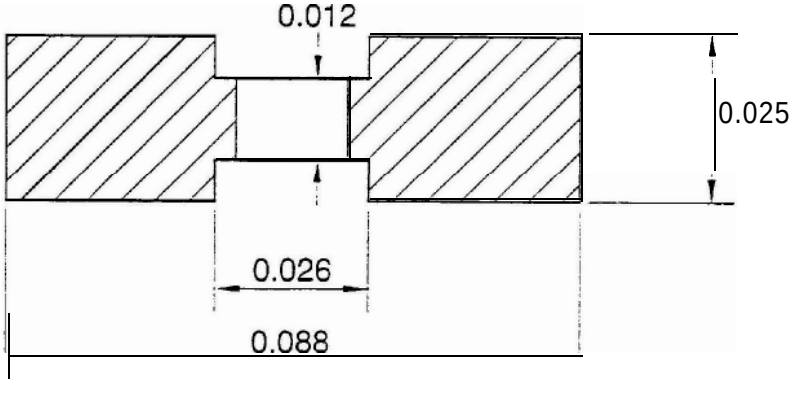
THE MITEE REACTOR ASSEMBLY



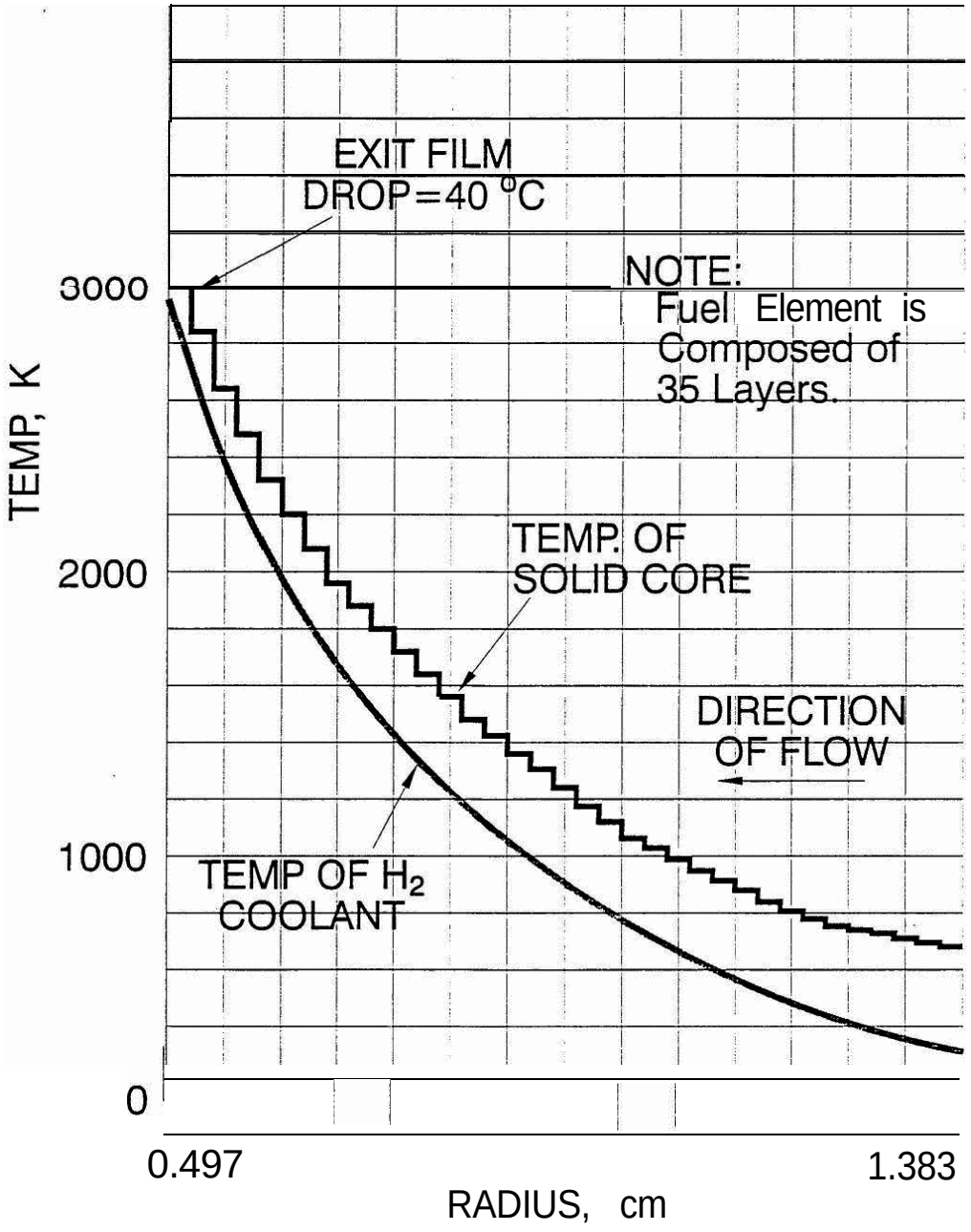
FUEL SHEET GEOMETRY FOR HEAT TRANSFER ANALYSIS



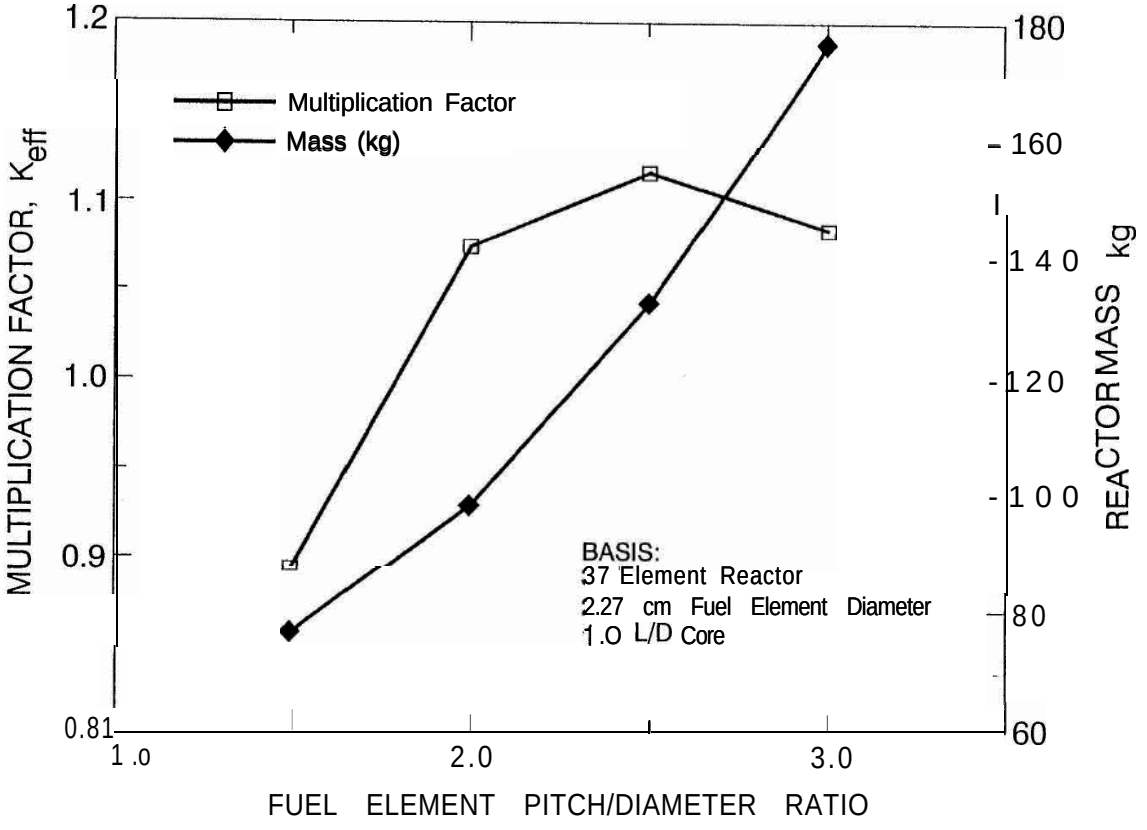
NOTE: ALL DIMENSIONS
ARE IN CM



TEMPERATURE VARIATION THROUGH FUEL REGION OF ANNULAR FUEL ELEMENT



VARIATION OF MULTIPLICATION FACTOR AND MASS WITH **MITEE** REACTOR FUEL ELEMENT PITCH/DIAMETER RATIO



Baseline MITEE Engine Parameters

PARAMETER	
Reactor Poker, MW	75
Coolant Pressure, MPa	7
Inlet/Outlet Temperature, K	30/3000
Power Density in Fuel Zone, MW/L	10
Thrust, Newtons	14,000 X
No. Fuel Elem./No. Reflector Elem.	37/24
Fuel Element OD/ID, cm	2.7711 .O
Moderator/Reflector Type	^{7}LiH/Be
Core/Reflector OD, cm	38.7/49.8
u-235 Mass	23.2
k_{eff}	1.07
ENGINE MASS, KG	
Reactor	100
Auxiliaries	36
Contingency	64
Total:	200

Figure 7

The MITEE Family of Nuclear Propulsion Engines

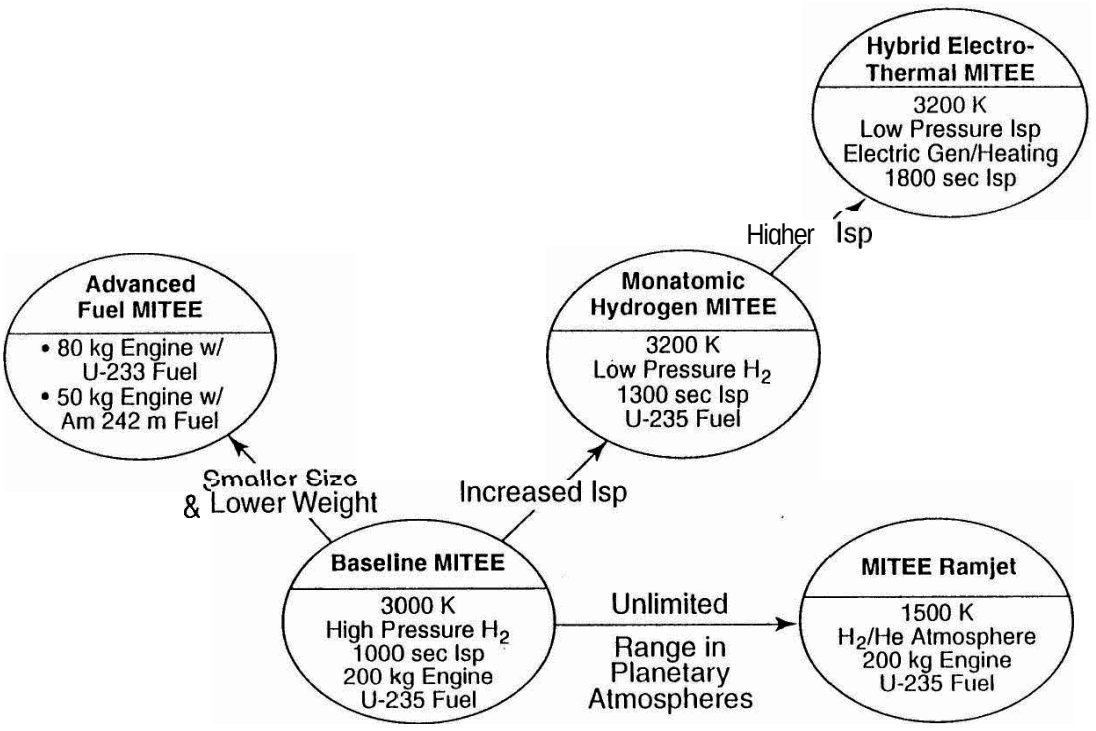


Figure 10

Criticality Constant (K_{eff}) vs MITEE Reactor Mass For Different Fissile Fuels and Core Configurations

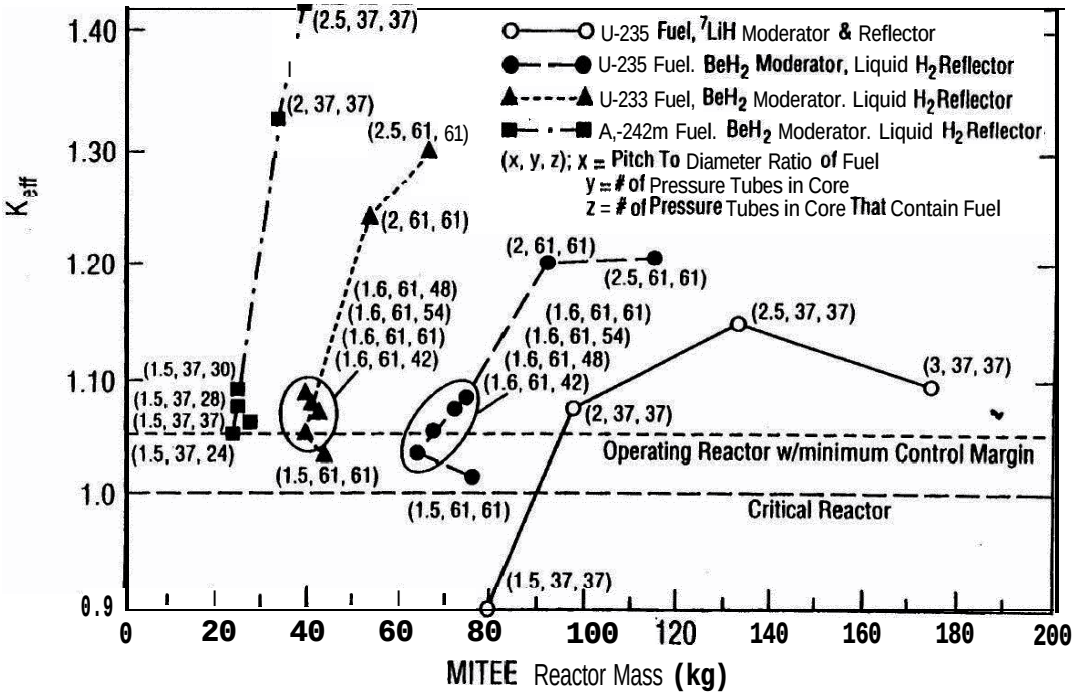


Figure 8

Summary of Reference MITEE Engines Utilizing High Performance Nuclear Fuels

Fuel	Reactor Mass	Approximate Engine Mass*
U-235	70 kg	140 kg
U-233	40 kg	80 kg
Am-242 m	25 kg	50kg

* Engine ~ 2 x Reactor Mass - Includes Turbo Pump, Controls, and Contingency

Figure 9

IMLEO As A Function of Burn AV For MITEE Engine Options

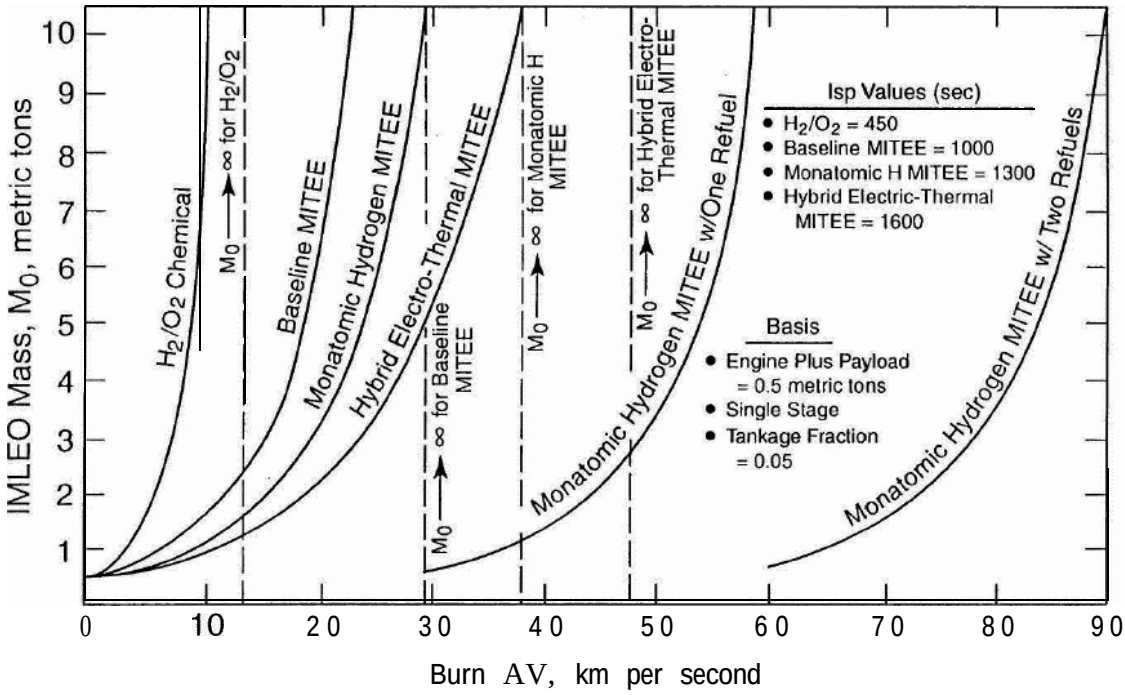
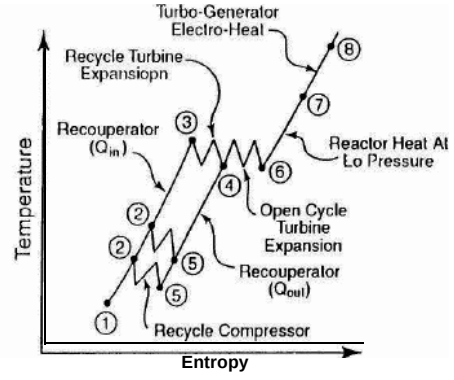


Figure 13

Temperature-Entropy Diagram and Flow Sheet For Recycle Hybrid Electra-Thermal MITEE Engine

Temperature-Entropy Diagram (2 Cycle Version)

Flow Sheet (2 Cycle Version)



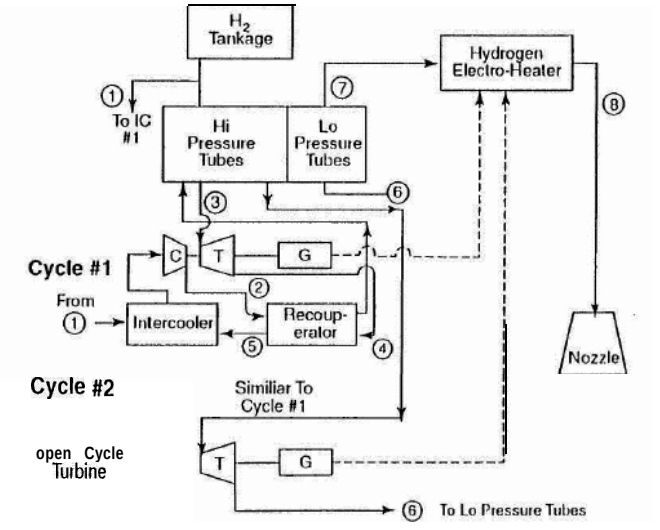
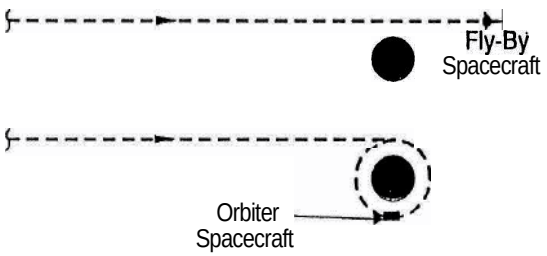


Figure4.4.2

Uniaue Planetarv Missions Enabled bv Nuclear Rockets

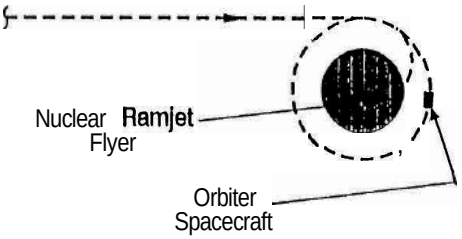
I. Fast Trip Fly-By and Orbital Capture Missions to Distant Bodies

Potential Missions: Planets (Pluto, etc.), Moons (Titan, etc.), Asteroids, Comets



II. Ultra Long Range Planetary Atmospheric Flyers

Potential Missions: Planets (Jupiter, Saturn, etc.), Moons (Titan, etc.)



III. Refuel Missions Using Extraterrestrial Propellant Resources to Extend Range or Return Samples

Potential Propellant Sources: Planets (Mare, etc.), Moons (Europa, Titan, etc.), Asteroids, Comets

IV. Orbit to Surface Shuttle Missions Using Extraterrestrial Propellant Resources

Potential Shuttle Missions: Planets (Mars), Moons (Earth, etc.)

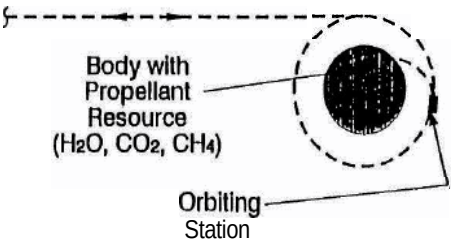
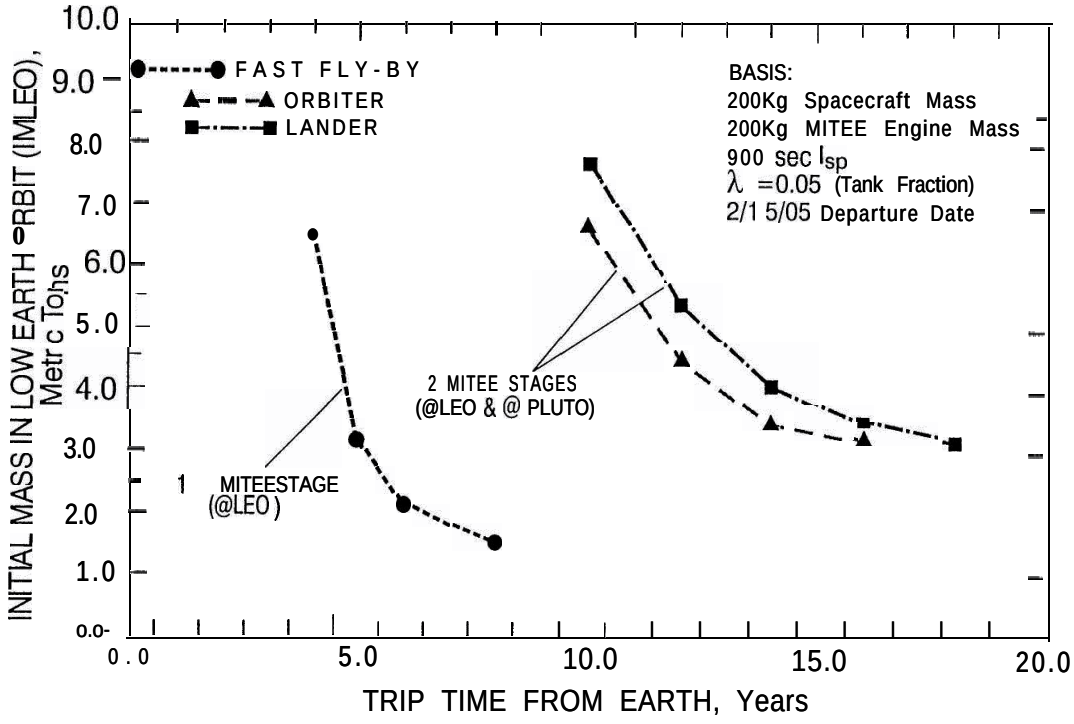


Figure I.2

Table 3. Examples of MITEE Solar System Missions

Destination/ Mission	Payload (kg)	Launch Date/Trip Time	Mission AV (km/s)	IMLEO (kg)	Launch Vehicle/ Approx. Cost
I. Pluto fly-by	200 (2 spacecraft @ 100 kg each)	2/15/05 1 years	11.82	1800	LMLV-3 ($25M)
2. Pluto orbiter	200	2/15/05 13 years	18.31	3985	Atlas IIAS ($100M)
3. Pluto lander	200	2/15/05 I4 year.3	17.59	4100	Atlas IIAS ($100M)
4. Jupiter orbiter & atmospheric flyer	200 (orbiter) 400 (flyer)	1/10/06 2 years	IO.77	3395	Delta II ($50M)
5. Saturn orbiter & atmospheric flyer	200 (orbiter) 400 (flyer)	10/5/06 3 years	12.37	4170	Atlas IIAS ($100M)
6. Europa lander/refuel/ sample return	200	1/10/06 2 years out 3 years ret.	13.53	4610	Atlas IIAS ($100M)
7. Pluto lander/refuel/ sample return	200	2/15/05 I2 years out I2 years ret.	19.65	9050	Titan IV ($100M)

PLUTO MISSIONS USING MITEE NUCLEAR ROCKETS



IMLEO vs. Delta V for Travel to 100 A.U.

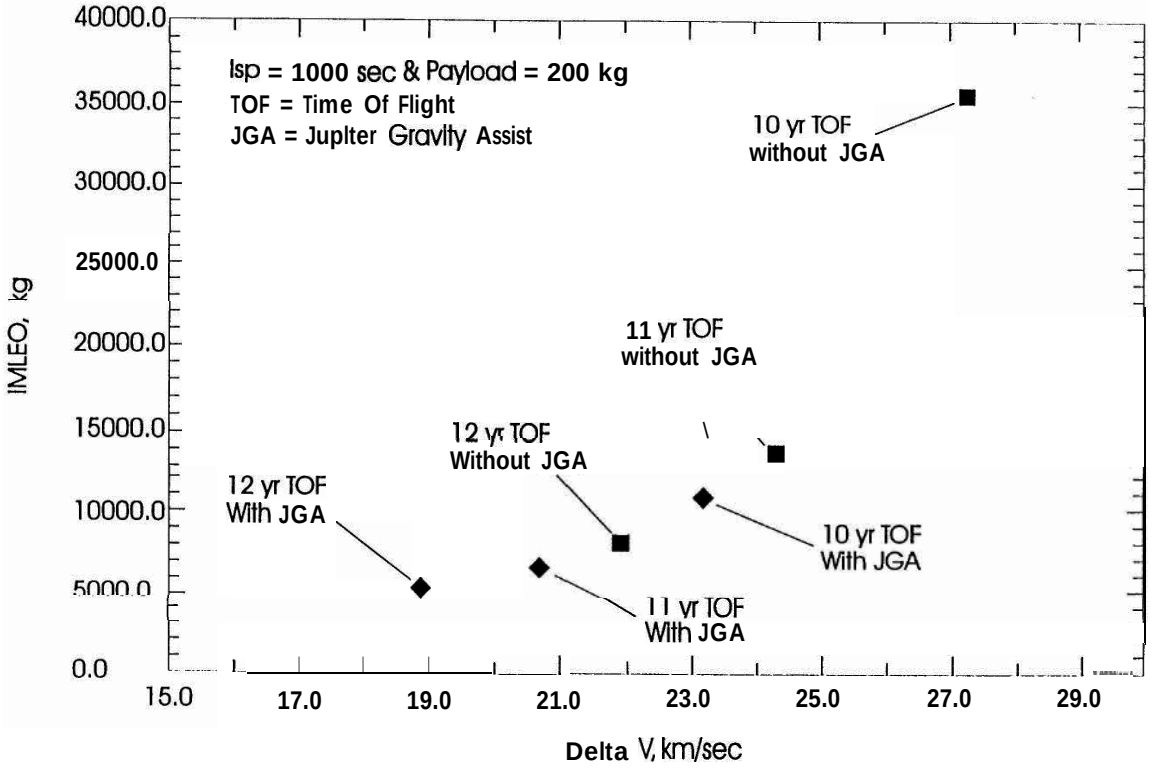
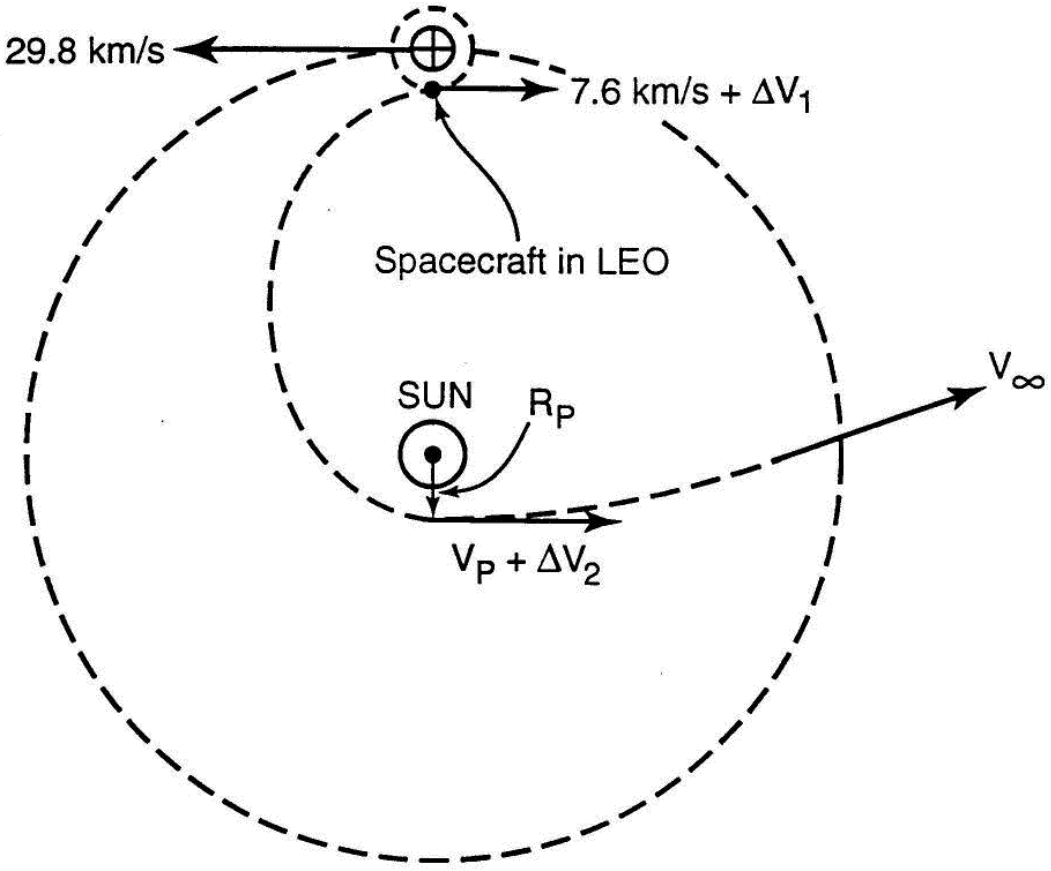


Illustration of SUNBURN Concept



NOTE: ΔV_1 Rocket Burn 1

ΔV_2 Rocket Burn 2

Figure 18

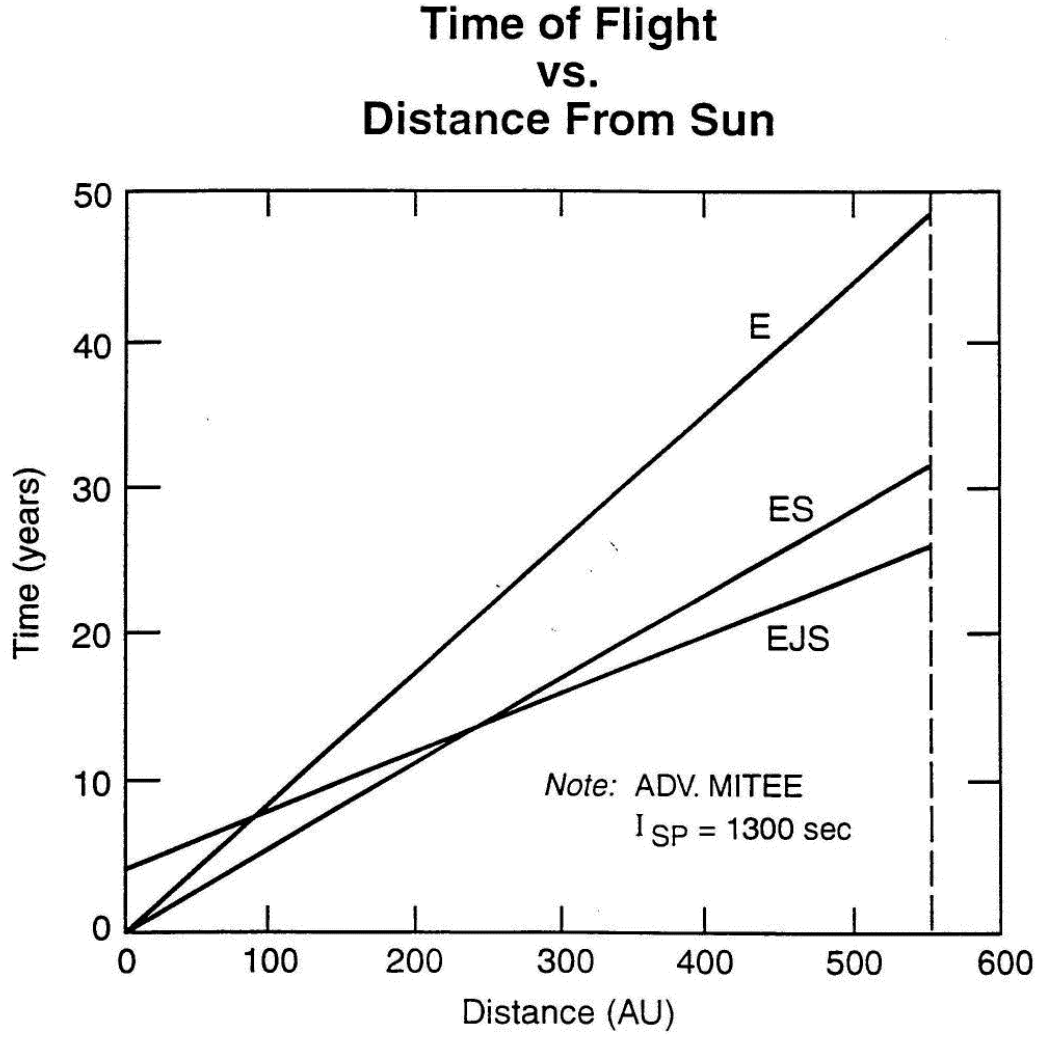

Time of Flight
vs.
Distance From Sun
Time (years)
50
40
30
20
10
0
0
100
200
300
400
500
600
Distance (AU)
E
ES
EJS
Note: ADV. MITEE
I SP = 1300 sec

Figure 19

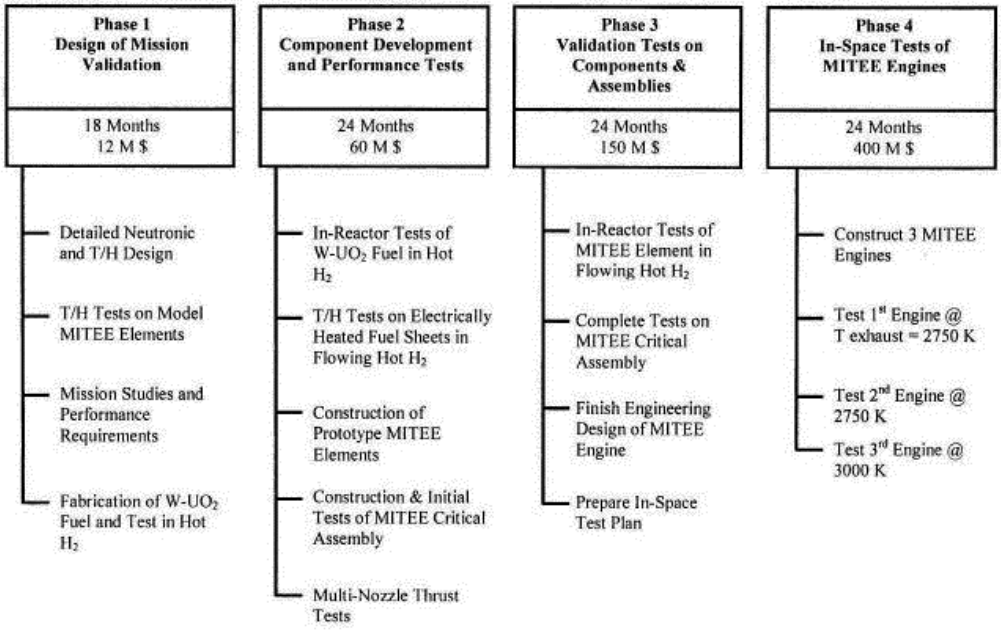
Goals for Space Nuclear Propulsion

- Safe and Acceptable System
- Operational by 2008
- Modest Development Cost (< 1B $)
  - » Builds on Existing Technology
  - » Minimizes Need for New Test Facilities
- Enables Major Performance Gains
  - » Shorter Trip Times
  - » Wider Mission Windows (e.g., No Planetary Gravity Assists)
  - » Smaller Launch Vehicle
  - » Enables Important New Missions Not Possible Now
- Suitable for Wide Range of Future Space Missions
  - » Planetary Science Missions w/Small Spacecraft (-100 to 200 kg)
  - » Eventual Manned Missions
- High Reliability
  - » Operates Well Below Max Temperature, Burnup, Thermal Hydraulics, etc. Limits
  - » Short Operating Time
  - » Minimum Dependence on Auxiliary Systems (e.g., Electric Thrusters,, Power Conversion, Radiators, etc.)

How Well Does MITEE Meet these Goals?

- Clearly, MITEE Meets the Goals of
  - » Major Performance Gains
  - » Suitable for Wide Range of Missions
- MITEE Has the Potential for High Reliability Because
  - » W-UO, Fuel Has Demonstrated Excellent Resistance to Hot H_2 (3000 K) for Periods of Hours With Minimal Fuel Loss
  - » Operating Time is Typically Less Than 1 Hour, Compared to Years for NEP
  - » Does Not Need Auxiliary Power conversion, Radiators, and Electric Thruster Systems
- MITEE Development Program is Outlined That Enables
  - » A Safe, Acceptable System
  - » Operation by 2008
  - » R&D Costs < 1 B $
  - » Minimal New Test Facilities

Principal Reactor Task Areas for MITEE Development Program



Summary and Conclusion

- Baseline MITEE Engine Very Promising for Outer Planetary Missions
  - » Very Lightweight (-200 kg), High Specific Impulse (-1000 sec)
  - » Much Shorter Mission Times
  - » Gravity Assists Not Needed
  - » Lower Cost Launch Vehicles
  - » Enables Many New and Unique Missions
- W/UO_2 Fuel Has Operated for Hours in 3000 K Hi Pressure Hydrogen
- MITEE Fuel Element Thermal Hydraulics Less Demanding Than PBR Which Demonstrated 30 MW/Liter Performance in Blow-Down Tests
- MTTEE Pressure Tube Design Greatly Simplifies Reactor Development and Testing - Focus on Single Tube Tests, Both Non-Nuclear and Nuclear
- MITEE Engine Could be Ready by 2008